REVIEW

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ELASMOBRANCH RESEARCH IN PARANÁ STATE: A FOUR-DECADE REVIEW

Pesquisa com elasmobrânquios no estado do Paraná:
uma revisão de quatro décadas

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ABSTRACT

The present study diagnosed the state of the art of elasmobranch research in the State of Paraná, Southern Brazil. Through a systematic literature review, 220 studies with elasmobranchs in the State were retrieved. Studies began in the 1980s, reaching a peak between 2010 and 2019. When the publication categories were considered separately, a predominance of peer-reviewed papers was noted. However, when grouping grey literature categories, this type of document was predominant, indicating that many of the investigations carried out were neither peer-reviewed, nor published in indexed databases. The most representative research areas were fisheries (18%) and feeding (13%). A total of 75 species belonging to 40 genera were investigated, with most studies focused on *Carcharhinus* spp. (n = 60), *Sphyrna* spp. (n = 40), *Pseudobatos* spp. (n = 35), and *Zapteryx brevirostris* (n = 29). Some research trends in Paraná were like those identified for both South American and global scenarios, namely feeding ecology and fisheries. Nevertheless, some research areas that are key to be considered for adequate elasmobranch management and conservation measures were systematically neglected or remained underdeveloped in the State. Furthermore, for most species (e.g., *Galeocerdo cuvier, Rhizoprionodon* spp., *Squatina* spp., *Narcine brasiliensis*, *Hypanus guttatus*), information on basic biology and ecology are

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still lacking, indicating the need for future studies focusing on generating data for this important global elasmobranch conservation hotspot.

Keywords: rays, sharks, studies, priorities, Southern Brazil.

RESUMO

O presente estudo diagnosticou o estado da arte da pesquisa com elasmobrânquios no estado do Paraná, no Sul do Brasil. Por meio de revisão sistemática da literatura, foram recuperados 220 estudos com elasmobrânquios no estado. Os estudos começaram na década de 1980, atingindo um pico entre 2010 e 2019. Quando as categorias de publicação foram consideradas separadamente, notou-se uma predominância de artigos revisados por pares. No entanto, ao agrupar as categorias da literatura cinza, esse tipo de documento foi predominante, indicando que muitas das investigações realizadas não foram revisadas por pares nem publicadas em bases de dados indexadas. As áreas de pesquisa mais representativas foram pesca (18%) e alimentação (13%). Um total de 75 espécies pertencentes a 40 gêneros foram investigados, com a maioria dos estudos focados em Carcharhinus *spp. (n = 60),* Sphyrna *spp. (n = 40),* Pseudobatos *spp. (n = 35) e* Zapteryx brevirostris *(n = 29). Algumas tendências de pesquisa no Paraná foram semelhantes àquelas identificadas para os cenários sul-americano e global, a saber, ecologia alimentar e pesca. No entanto, algumas áreas de pesquisa que devem ser consideradas para o manejo adequado e medidas de conservação dos elasmobrânquios foram sistematicamente negligenciadas ou permaneceram subdesenvolvidas no estado. Além disso, paraamaioriadasespécies (por exemplo,* Galeocerdo cuvier, Rhizoprionodon *spp.,* Squatina *spp.,* Narcine brasiliensis, Hypanus guttatus*), ainda faltam informações sobre biologia básica e ecologia, indicando a necessidade de estudos futuros com foco na geração de dados para esse importante hotspot de conservação de elasmobrânquios.*

Palavras-chave: *raias, tubarões, estudos, prioridades, Sul do Brasil.*

INTRODUCTION

The State of Paraná is located in Southern Brazil, bordering the states of Santa Catarina, São Paulo and Mato Grosso do Sul, in addition to having borders with provinces of Argentina and Paraguay (IBGE, 2020). The State has a territorial area of 199.298.982 km², with the second smallest coastline in the country (IBGE, 2020). The coast is facing east in the Atlantic Ocean and is about 100 km long, with about 68 beaches and several islands (Bigarella, 2001; Bornatowski & Abilhoa, 2012). The continental shelf of the State is considered extensive and shallow and comprises the Estuarine Complex of the bays of Paranaguá (PEC) and Guaratuba, both components of an interconnected subtropical estuary system that also includes the Iguape-Cananéia System on the southern coast of the State of São Paulo (Lana *et al.*, 2001; Angulo *et al.*, 2016). The PEC is considered the largest estuary in Southern Brazil and is also listed as a world heritage site by the United Nations Educational, Science and Culture Organization (Unesco, 1999). In addition, the State also has a complex network of hydrographic basins, comprising the Paraná, Paranapanema and Iguaçu river basins (Governo do Estado do Paraná, 2015).

Due to physiographic aspects, the coast of Paraná has a diversity of environments, such as mangroves, marshlands, and sandy beaches, harboring a great diversity of species and functioning as a shelter, feeding, reproduction and nursery area for many species (Lana *et al.*, 2001; Noernberg *et al.*, 2006; Brandini, 2013). Likewise, the rivers that flow through the State are rich in biodiversity (Agostinho; Thomaz & Gomes, 2005; Agostinho *et al.*, 2018). Paraná can be considered an elasmobranch hotspot, as it has a relatively high abundance of species. Altogether, approximately 51 species of sharks, and 32 species of batoids, have been recorded in this region (Bornatowski; Abilhoa & Charvet-Almeida, 2009). Although most species are coastal and marine, in Paraná there are also Neotropical freshwater stingrays (Potamotrygoninae) records of occurrence in the Paraná-Prata River Basin (Rosa; Charvet-Almeida & Quijada, 2010; Last *et al.*, 2016). Until the 1970s, freshwater stingrays' upstream distribution area in the Paraná River Region was limited by the Sete Quedas Waterfalls, located in the Municipality of Guaíra. After the flooding of this natural barrier due to the implementation of the Itaipu Hydroelectric Power Plant reservoir in the early 1980s, these inland elasmobranch species colonized and expanded their geographic distribution upstream in the Paraná River Basin (Garrone-Neto *et al.*, 2007).

In addition to the great biodiversity, Paraná also has a large human population (estimated at 11,08 million people) (IBGE, 2021), with significant growth and urbanization in recent years, especially in the coastal region (Angulo; Souza & Noernberg, 2020). With an estimated total population of 302.544 inhabitants, the coastal region of Paraná has more than 60 fishing communities and about 6000 fishers residing in six municipalities (Andriguetto Filho *et al.*, 2006; IBGE, 2020; Iapar-Emater, 2021). Moreover, fishing activities also take place in continental waters, especially in the basins of the Paraná, Paranapanema, Tibagi and Ivaí rivers (Iapar-Emater, 2021). In general, fisheries in the region are artisanal, with a variety of fishery practices and target species (Afonso & Chaves, 2021; Andriguetto Filho *et al.*, 2006; Chaves; Pichler & Robert, 2002). However, fishing fleets from neighboring states, such as Santa Catarina, also fish in Paraná waters (Andriguetto Filho; Krul & Feitosa, 2009).

The Paraná coast is home to 57.3% of the shark species and 45.7% of the marine rays recorded in Brazil (Bornatowski & Abilhoa, 2012). To date, freshwater stingray's occurrence records in Paraná State are available for *Potamotrygon falkneri*, *Potamotrygon motoro* (Garrone-Neto *et al.*, 2007), *Potamotrygon amandae* and *Potamotrygon histrix* (Charvet, P., unpublished data), or approximately 10% of the described species to date. Among the elasmobranch species that occur in the State, many are classified as threatened both by the International Union for Conservation of Nature (IUCN) and the Brazilian Red Lists. Additionally, the State is home for endemic species, and along with Santa Catarina, Rio Grande do Sul, Uruguay and Argentina, is listed as a conservation hotspot (Lucifora; García & Worm, 2011; Davidson & Dulvy, 2017; Derrick; Cheok & Dulvy, 2020). Although elasmobranchs are not usually a target resource, they are part of the bycatch of several regional fisheries (Costa & Chaves, 2006; Chaves; Almeida & Platner, 2019). Nevertheless, at some times along the year, especially during the summer, certain species are targeted, such as carcharhinid sharks (Bornatowski *et al.*, 2011; Chaves; Almeida & Platner, 2019). Data collected between 1980 and 1994 showed that about 6.4% of the total artisanal fisheries production in Paraná was made up of elasmobranchs, surpassing the catches of commercially important teleosts such as the weakfish *Cynoscion* spp. ("pescada") and mullets *Mugil* spp. ("tainha") (Paiva, 1997).

Although listed as small-scale, marine elasmobranch commercial captures in the State can be very expressive, as reported in 2009, when in a single fishing community, the production exceeded 13 tons (Chaves; Almeida & Platner, 2019). During spring, pregnant females of the Scalloped Hammerhead (*Sphyrna lewini*), Blacktip (*Carcharhinus limbatus*) and Dusky Shark (*Carcharhinus obscurus*) approach the coast, negatively interacting with artisanal fisheries (Bornatowski & Abilhoa, 2012). During summer, neonates and juveniles of the above-mentioned species are regularly captured in large quantities. Smooth Hammerhead Shark (*Sphyrna zygaena*) juveniles are caught during winter and early spring, while Tiger Shark (*Galeocerdo cuvier*) pregnant females and juveniles are caught mostly in the spring (Bornatowski & Abilhoa, 2012). The Brazilian Sharpnose Shark (*Rhizoprionodon lalandii*) interacts constantly with artisanal fisheries, since at all life stages it exhibits coastal habits, being regularly landed in Paraná throughout the year. Occasional captures of Grey Nurse (*Carcharias taurus*), Shortfin Mako (*Isurus oxyrinchus*) and Bigeye Thresher (*Alopias superciliosus*) sharks are also reported for the region (Bornatowski & Abilhoa, 2012). Fishing records also indicate the use of the Paraná Coast as parturition and nursery areas for the Chola Guitarfish (*Pseudobatos percellens*), the Shortnose Guitarfish (*Zapteryx brevirostris*), and the Blacktip Shark (Bornatowski & Abilhoa, 2009).

Freshwater stingrays are found in the Amazon, Parnaíba and Paraná-Prata hydrographic basin drainages in Brazil. Negative interactions with fishers, riparian communities and tourists have already been reported for the Paraná-Prata Basin (Junior; Cardoso & Neto, 2013; Santos *et al.*, 2019), however, data on commercial capture and other anthropogenic impacts on potamotrygonin populations in the State of Paraná are scarce, preventing an accurate diagnosis of the current situation of freshwater stingrays in the region.

Southern Brazil was first listed as a conservation hotspot in 2011 due to the high level of endemic elasmobranchs in the region (Lucifora; García & Worm, 2011). The importance of this region to the global scenario was recently confirmed by Dulvy *et al.* (2021), indicating the urgent need for studies in this hotspot. As mentioned above, the State is home to an expressive number of species found at the national level (Bornatowski & Abilhoa, 2012), despite exhibiting the second smallest coast in the country. As for freshwater species, despite their ecological and medical importance (Rosa *et al.*, 2010), there are limited studies in Paraná's riverine habitats and the need for management and conservation actions for these endemic but potentially invasive species cannot be discarded. Given the relevance of Southern Brazil for elasmobranch conservation, it is important to map and characterize previous studies carried out in the region, aiming to create a database that could be used for both researchers and policy makers. Investigations based on the State of the Art (SoTA) approach are needed, since with a systematic review of available studies it is possible to direct conservation measures and also point out knowledge gaps that future projects must focus on. Within this context, this study outlines the research carried out with elasmobranchs in the State of Paraná to date. It diagnoses the main areas of interest and study, as well as their strengths and weaknesses.

MATERIAL AND METHODS

The search carried out per year or decade, research area and species only considered data published in peer-reviewed journals. Furthermore, an additional temporal analysis also included non-peer reviewed information from other sources (e.g., monographs, thesis, dissertations, and conference abstracts) to cover the trends in past studies advances.

Published papers were searched primarily in indexed databases, including Google Scholar, Scopus, and Web of Science. A systematic review following the methods proposed by Greenhalgh and Peacock (2005) was performed through active search. The search was done exclusively in the virtual environment through a structured Boolean search (AND, OR, +) was performed using the following search terms: "Elasmobranch", "Paraná State", "Shark", "Ray", "Southern Brazil". Then, a snowball method was applied to search for additional publications from the reference lists. As some papers were published in Portuguese, the systematic review included a secondary search (i.e., "Elasmobrânquios", "Paraná", "Tubarão", "Raia", "Sul do Brasil"). Entries from all years were considered. A search for grey literature was also performed in State university databases (for undergraduate monographs, thesis, and dissertations), as well as in conferences' abstract books available online. Specifically for the abstracts, meetings of the Brazilian Society for the Study of Elasmobranchs (SBEEL), Brazilian Society of Ichthyology (SBI), and Sharks International Conferences (2014 and 2018) were prioritized. A secondary search for other conferences was also carried out, including the Latin American Congress of Marine Sciences (COLACMAR), the Colombian Meeting on Chondrichthyes, the Scientific Meeting of the European Elasmobranch Association, the International Congress for Conservation Biology, the Brazilian Congress of Oceanography, the International Marine Conservation Congress, and the International Meeting on Amazonian Sharks and Batoids.

All information obtained was compiled in a data spreadsheet, including year of publication, authors, title and research area. Entries were also sorted according to the type of document, being classified as: peer-reviewed papers, technical reports, doctoral dissertations, master's thesis, monographs, and conference abstracts. An initial reading focusing on the information contained in each abstract was carried out to classify them according to their research area. When necessary, a more careful reading of the entire text was performed, to collect more detailed information. Additionally, all studied species were mapped considering the current nomenclature based on Ebert and Fowler (2013) and Last *et al.* (2016). Synonyms were also considered and highlighted in the sheet along with the most recent nomenclature.

A secondary analysis was then performed to delete double entries, considering studies that were included as grey literature but had already been published in peer-reviewed journals. Priority was given to the study published in English and grey literature entry was deleted. The data was qualitatively analyzed, aiming at a diagnosis of the state of the art and the identification of patterns in the studies carried out. More specifically, the studies were analyzed in terms of temporal distribution, document category, species studied, and investigation topic. When more than one investigation topic (i.e., research area) was identified for the same study, both were considered.

RESULTS

A total of 220 elasmobranch studies were identified for the State of Paraná. Most of them corresponded to peer-reviewed publications, both in English and Portuguese (Figure 1). Conference abstracts were also very representative, in both languages, but with a higher incidence of abstracts in Brazilian Portuguese. As for investigations carried out by students, the main portion referred to monographs, and a smaller portion to masters' thesis and PhD dissertations. Considering the "student category", most studies were written in Brazilian Portuguese (Figure 1).

Figure 1 – Representativeness (in percentage) of each overall category of elasmobranch research in the State of Paraná, Southern Brazil. Data from 1985 to 2021.
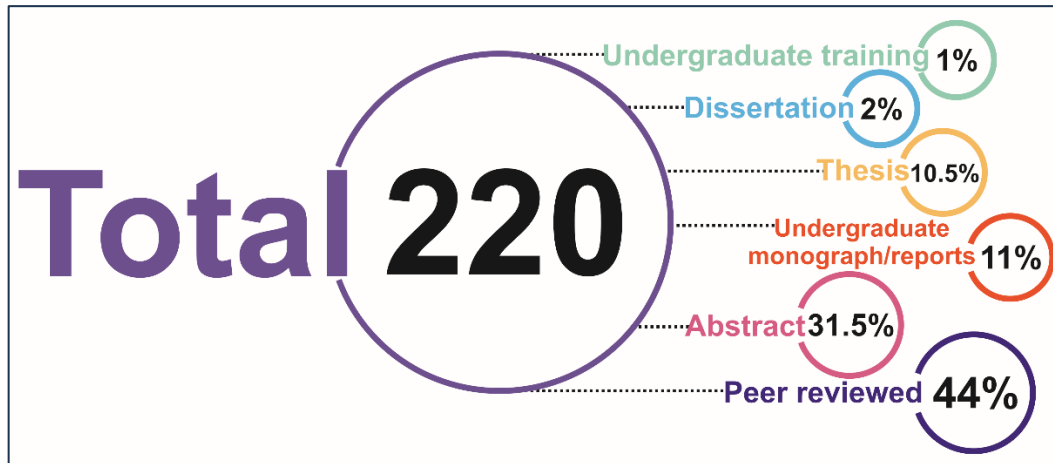

Taken together, grey literature (i.e., undergraduate monographs, thesis, dissertations and conference abstracts) entries represented the largest intellectual regional productivity on elasmobranchs, indicating that many of the investigations carried out were not peer- reviewed, nor published in indexed databases. In addition, a large portion of the studies carried out by students corresponded to monographs, which in Brazil are a requirement for completion of undergraduate university courses. Studies developed by graduate students, when analyzed separately, represent a smaller portion, with more masters than doctoral students working with sharks and batoids in the State.

Temporal dispersion

The first study on elasmobranchs recovered dates back to 1985, while the most recent is from 2021. When categorized by decades, a growing trend of studies was noted. From the 80's to the beginning of the 2000's, only 6% of the total retrieved studies were developed (Figure 2). It was from 2001 on those investigations on elasmobranchs in the region became more expressive, with a peak between 2010 and 2019. As for peer-reviewed papers, in the 1980s, only one paper was published. In the 90's, there were five publications. From 2000 to 2009, 32 peer-reviewed papers were retrieved and in the 2010s, there were 46 papers published. From 2020 to 2021, 13 studies were published.

Figure 2 – Temporal distribution in percentage of peer-reviewed with elasmobranchs carried out in the State of Paraná. Each interval corresponds to a decade. Data from 1985 to 2021.
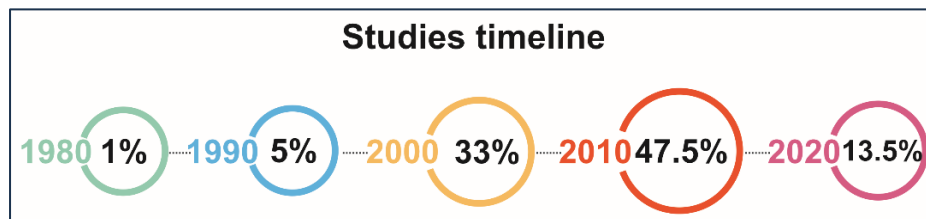
Additionally, when considering non-peer reviewed conference abstracts, in the 1980s, two documents were identified, both from the same research group (Corrêa, M. - laboratory head). In the 1990s, 13 abstracts were recovered, the majority by the same author (Charvet, P.). There was a significant reduction in the number of abstracts in the 2000s, with only nine documents identified. The largest portion of conference abstracts was observed from 2010 onwards (up to 2020), with a total of 45 documents retrieved. During this period, a greater diversity of authors, and also a greater representation of women as leading authors was noted. Lastly, as for monographs, thesis and dissertations, there were no records for the 80s, three records for the 90s, 17 records for the 2000s, and 34 records from 2010 onwards. Interestingly, it was only in 2006 that the first doctoral dissertation on elasmobranchs was produced, and in 2007 that the first master's thesis was recorded, indicating that postgraduate projects with elasmobranchs in Paraná only began to be developed in the early 2000s.

Research area

A total of 22 research areas were identified, covering a wide spectrum of topics (Figure 3). Most studies performed with elasmobranchs in Paraná referred to fishing (18%), followed by feeding (13%). Although less expressive, studies reporting species occurrence (9%), and physiology (7%) were also carried out, along with biology, morphology, and parasitology (6% each). Ecological studies were also developed (5%), but to a lesser extent, as well as studies on elasmobranch reproduction (5%), conservation, genetics and species checklist (4% each). Interestingly, even though considered relevant topics today, only 2% of the studies were on elasmobranch consumption and toxicology. Moreover, legislation was also systematically underrepresented, corresponding to only 1% of investigations carried out since the 1980s.

Figure 3 – Research trends on elasmobranchs in Paraná over the last four decades. Peer-reviewed papers data from between 1985 to 2021
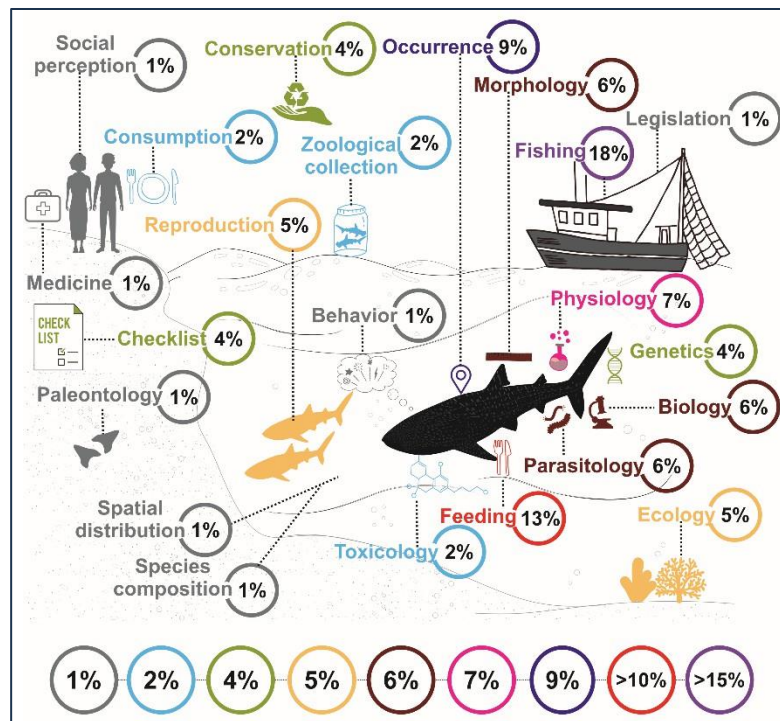
As most investigations performed in Paraná rely on artisanal fisheries, some of the studies recovered were classified in more than one research area (e.g., reproduction + fishery). Nevertheless, the topic was considered only when relevant to the discussion of results (i.e., in a study where fishing was cited solely as a method for obtaining samples, the category "fishing/ fishery" was not considered). In addition, many ichthyofauna survey studies were carried out in the region by several research groups, however, these were excluded from the analysis and only occurrence/checklist studies focused on elasmobranchs were considered.

Species studied

A total of 75 species belonging to 40 genera were investigated in Paraná, with a predominance of shark species over batoids (Figure 4). In some studies, identification at species level was not possible, so data was evaluated at species level whenever available. Interestingly, most of studies are multispecies (n = 53), while single-species studies are mostly focused on *Zapteryx brevirostris* and *Pseudobatos* spp. Moreover, while multispecies studies are manly focused on diet/feeding ecology, catch composition and checklists, single-species studies are focused on diet, reproduction, commercial fishing and physiology.

Considering the most studied genus *Carcharhinus* (60 studies), the most prevalent species was C. *obscurus* (15 studies) followed by *C. limbatus* (11 studies). For all *Carcharhinus* species investigated in the region, most studies are focused on diet/ feeding ecology, followed by catch composition. As for the genus *Sphyrna*, *S. lewini* was the most studied species (n = 20), followed by *S. zygaena* (n = 16), *S. mokarran* (n = 2) and *S. tiburo* and *S. tudes* (one study each). Most studies on *Sphyrna* species also focused on diet/feeding ecology and catch composition, followed by parasitology and meat consumption. Studies on reproduction, physiology, morphology are very scarce for all species belonging to both genera. In the case of the genus *Pseudobatos*, a predominance of studies focusing on *P. percellens* (n = 28) over *P. horkelii* (n = 7) was noted. Most studies on *Pseudobatos* spp. are focused on catch composition, diet/feeding ecology and reproduction. In the case of *Zapteryx brevirostris* (29 studies), both multi-species and studies focused only on this guitarfish were observed, mainly on catch composition, diet, physiology and conservation.

As for other species such as *Hypanus* spp. (4.9%), *Rhizoprionodon* spp. (4.7%), *Atlantoraja* spp. (4.4%), *Rhinoptera* spp. (4.4%), *Squatina* spp. (4.4%), *Galeocerdo cuvier* (3.8%), *Narcine brasiliensis* (3.8%), *Potamotrygon* spp. (3.3%), *Mustelus* spp. (3.1%), *Gymnura altavela* (2.4%), *Rioraja agassizii* (2.4%), *Carcharias taurus* (2.2%), *Isurus* spp. (2%), *Prionace glauca* (2%), *Myliobatis* spp. (1.3%), *Dasyatis hypostigma* (1.1%), *Galeorhinus galeus* (1.1%), *Mobula* spp. (1.1%) and *Squalus* spp. (1.1%), most studies are focused on catch composition and checklist/occurrence, and basic information on their biology and ecology are severely lacking. The least studied elasmobranchs are *Aetobatus narinari* (0.9%), *Alopias* spp. (0.9%), *Dipturus trachyderma* (0.9%), *Heptranchias perlo* (0.9%), *Scyliorhinus* spp. (0.9%), *Sympterygia* spp. (0.9%), *Hexanchus griseus* (0.7%), *Pteroplatytrygon violacea* (0.7%), *Bathytoshia centroura* (0.4%), *Carcharodon carcharias* (0.4%), *Lamna nasus* (0.4%), *Notorynchus cepedianus* (0.4%), *Schroederichthys bivius* (0.4%), *Centrophorus squamosus* (0.2%), *Pseudocarcharias kamoharai* (0,2%), *Rhincodon typus* (0.2%), and the non-native *Triaenodon obesus* (0.2%), configuring another huge knowledge gap in the region (Figure 4).

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Figure 4 – Descending order of species predominance in studies carried out in Paraná, using only data from peer-reviewed papers from 1985 to 2021. *Carcharhinus* spp. (13.3%), *Sphyrna* spp. (8.9%), *Pseudobatos* spp. (7.8%), *Zapteryx brevirostris* (6.4%), *Hypanus* spp. (4.9%), *Rhizoprionodon* spp. (4.7%), *Atlantoraja* spp. (4.4%), *Rhinoptera* spp. (4.4%), *Squatina* spp. (4.4%), *Galeocerdo cuvier* (3.8%), *Narcine brasiliensis* (3.8%), *Potamotrygon* spp. (3.3%), *Mustelus* spp. (3.1%), *Gymnura altavela* (2.4%), *Rioraja agassizii* (2.4%), *Carcharias taurus* (2.2%), *Isurus* spp. (2%), *Prionace glauca* (2%), *Myliobatis* spp. (1.3%), *Dasyatis hypostigma* (1.1%), *Galeorhinus galeus* (1.1%), *Mobula* spp. (1.1%), *Squalus* spp. (1.1%), *Aetobatus narinari* (0.9%), *Alopias* spp. (0.9%), *Dipturus trachyderma* (0.9%), *Heptranchias perlo* (0.9%), *Scyliorhinus* spp. (0.9%), *Sympterygia* spp. (0.9%), *Hexanchus griseus* (0.7%), *Pteroplatytrygon violacea* (0.7%), *Bathytoshia centroura* (0.4%), *Carcharodon carcharias* (0.4%), *Lamna nasus* (0.4%), *Notorynchus cepedianus* (0.4%), *Schroederichthys bivius* (0.4%), *Centrophorus squamosus* (0.2%), *Pseudocarcharias kamoharai* (0,2%), *Rhincodon typus* (0.2%) and *Triaenodon obesus* (0.2%).
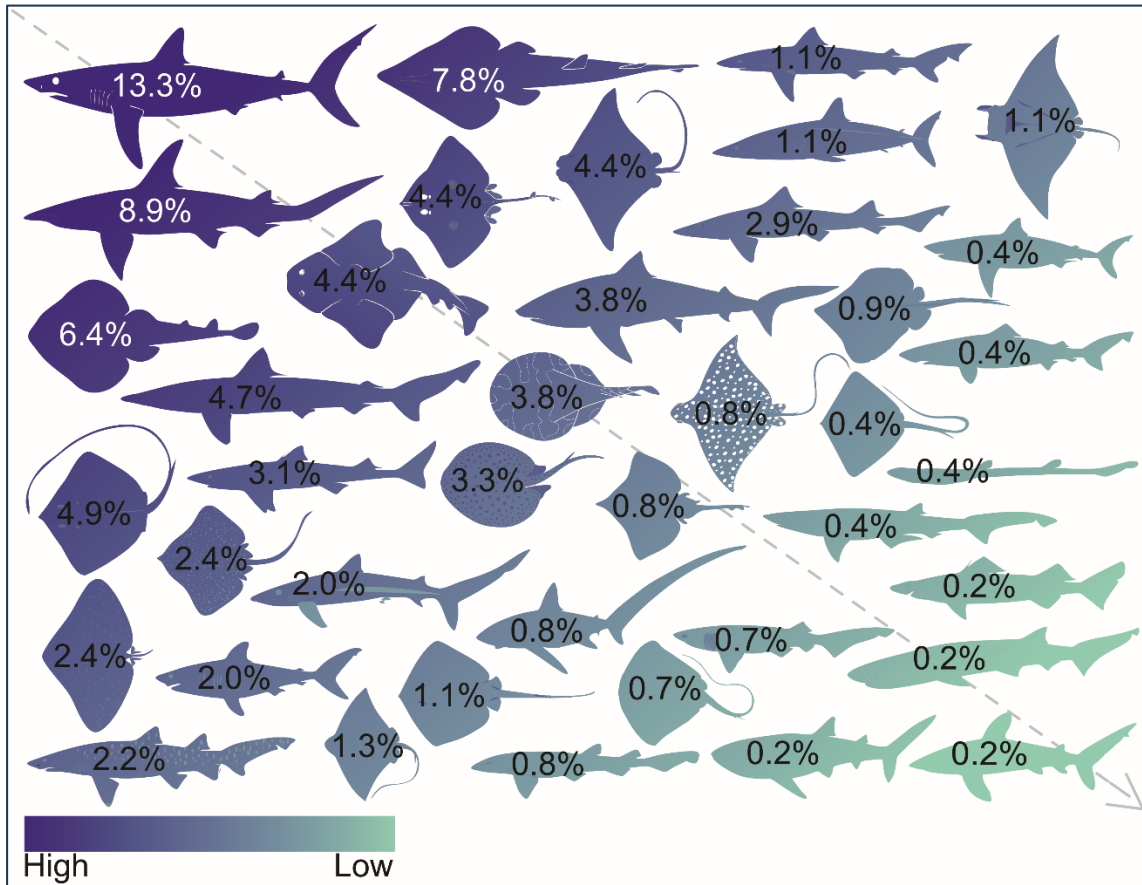
DISCUSSION

This is the first state of the art investigation on elasmobranch research in Paraná, and key information was obtained to help guide future studies, considering present status, knowledge gaps and data needed to regionally improve species management. When it comes to investigations focused on biodiversity conservation, National Plans of Action are considered promising tools to inform educational and research institutions, NGOs and conservationists on the priorities of a given region or taxonomic group (Davis & Worm, 2013; FAO, 1999, 2012). In Brazil, the National Action Plan for the Conservation of Threatened Marine Sharks and Rays ("Pan-Tubarões", or Sharks NPOA) was developed by specialists along with the Chico Mendes Institute for Biodiversity Conservation (ICMBio). It contains a list of species for which conservation measures are a priority, as well as a set of objectives and actions covering aspects that must be taken into account for the proper management of marine elasmobranchs in Brazilian waters. This is an important tool, but little explored by both

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researchers and conservation institutions/NGOs, since much of the data needed to implement management measures is still lacking. Along with the Sharks NPOAs, SoTA investigations and regional technical reports are also valuable tools to inform researchers what data should be prioritized in a given region/taxonomic group. The results of the diagnosis provided by the present study led to a critical analysis of research trends with sharks and batoids in Paraná, in addition to emphasizing knowledge gaps and suggesting future directions, based on data available to date and on further information needed to improve elasmobranch management and conservation in the region.

Until now, most, if not all, of the studies carried out in Paraná relied on commercial fisheries to obtain samples, more specifically on artisanal fisheries. Although fishing in the region is very dynamic (i.e., many different fishing gears being used interchangeably, as well as fishing regions being rotated at different times of the year) and operates all year round (Costa & Chaves, 2006; Cattani *et al.*, 2011; Oliveira Santos; Cattani & Spach, 2018; D'Ambrosio-Ferrari; Kotas & Spach, 2018; Afonso & Chaves, 2021), data that depends on commercial fishing can be somehow biased. This mainly because it can lead to regional species diversity underestimates, limit the type of studies that can be carried out (i.e., predominance of samples from dead or marketed animals) and directly influence investigations according to capture trends, considering that species seasonal captures do not allow continuous year-round investigations with some of them. That said, additional sampling methods are necessary, highlighting scientific fishing expeditions, recreational fishing data, and scientific diving expeditions, as well as underwater records made by divers or even remote video monitoring (i.e., BRUVs). However, it is important to mention that such methods may be difficult to incorporate due to weather conditions, and should be treated as complimentary rather than substitutes for studies based on commercial fishing.

Curiously, studies on freshwater stingrays rely not only on commercial fisheries but also on scientific fishing campaigns and scientific diving. It is possible that the greatest methodological advance in elasmobranch studies for inland waters may be related to both financial and operational challenges faced in the marine environment that are regionally not such a limiting factor for freshwater studies. However, once again, meteorological conditions also pose a challenge for inland studies in the region. Nevertheless, data is still scarce, and few investigations are being carried out to address points of concern, such as population dynamics, impacts of commercial fishing as well as mitigatory strategies for both incidents with humans, and the invasive potential of non-natural populations of endemic species.

When analyzing types of publication, peer-reviewed papers were predominant (44%), but only when considering grey literature categories separately. When grouped, abstracts, monographs, master's thesis, and PhD dissertations were the most representative (56%). This is of particular concern since grey literature is not peer-reviewed (although undergraduate and graduate documents are reviewed by a committee). Moreover, grey literature significantly reduces access to the data presented. In addition, most of the grey literature is available in Brazilian Portuguese, which further limits the access and dissemination of the data. That said, it is imperative to have regional research groups prioritizing peer-reviewed journals, which contribute to results validation, to disseminate research results and truly contribute to the management and conservation of the investigated species. Nonetheless, even if not all data that could be applied to management /conservation needs to be published in international journals or communicated to the academic

community, it is important that the data generated in the region be at least accessible as technical reports that can be directed to decision makers. In addition, it is key to make data available in a non-strictly-scientific-language, aiming to inform society about elasmobranch diversity, their role and ecological importance, as well as the need for conservation measures at the State level.

As for temporal trends, a growing interest in elasmobranch research was noted. In the first two decades (1980-1990), only six peer-reviewed papers were published, indicating a lack of investment/interest/access to elasmobranchs in the region. Elasmobranch research in Paraná began to become more expressive from the 2000s onwards, reaching its peak between 2010 and 2019. The same trend was observed in a survey carried out on the Brazilian Amazon Coast, where most studies with elasmobranchs were published from 2000 onwards (Coelho *et al.*, 2021). In fact, the representation of South America in the global elasmobranch research scenario between the years 2002 and 2016 was 11%, indicating an advance in this regard as well (Awruch; Somoza & Baldock, 2019). According to artisanal fishers, commercial fishing for elasmobranchs has been carried out in Paraná for more than 60 years, however, research only started in the late 1980s. At the global level, shark fishing began to raise concern only in the 80s (Thorson, 1987), which may at least partially explain the 25-year gap between shark fishing in the region and the first paper published. Furthermore, as elasmobranch conservation is now a global priority, the number of investigations for this decade (2021-2030) should be even more expressive.

In a paper published in 2019, Awruch and collaborators presented research trends with Chondrichthyes in South America for the last 50 years, indicating that fisheries, reproduction and taxonomy studies were the most carried out on the continent. In Paraná, the first investigations on elasmobranchs (1980s-1990s) aimed to describe species occurrence records for the region, in addition to elucidating non-reproductive morphological aspects. During this decade, in Paraná, a first study on shark age and growth aiming at fisheries management was carried out (Ferreira & Vooren, 1991), and since then, this has been the only study on this topic (i.e., age and growth) for sharks carried out in Southern Brazil, indicating a huge knowledge gap in this regard. As for batoids, two papers on age and or growth, comprising four species were retrieved (Oddone & Amorim, 2007; Carmo *et al.*, 2018). Since the 1980s, reproductive aspects were systematically neglected in Paraná, with information available only for a small portion of species in this region (Costa, 2004; Abilhoa; Bornatowski & Oliveira Freitas, 2007; Bornatowski, 2008; Oddone; Amorim & Mancini, 2008; Carmo, 2011). In fact, unlike the global and South American trends, where studies on reproduction and taxonomy were predominant (Awruch; Somoza & Baldock, 2019), in Paraná these areas of research were explored superficially, and very briefly. This is a concerning gap considering the importance of basic reproductive data for fisheries management, which hinders progress in proposing adequate measures for regional elasmobranch conservation. A possible explanation for such knowledge gap is that in Paraná most elasmobranchs are landed beheaded and gutted (Wosnick *et al.*, 2020), preventing researchers from collecting samples needed for these investigations (i.e., gonads and/or whole animals for taxonomic studies). Another aspect that poses a challenge for reproductive studies is that gonads tend to degrade with specimens handling by fishers and when exposed to higher temperatures after landings take place. However, it is not possible to rule out that the lack of studies on certain topics (reproduction included) is just a reflection of the lack of researchers interested in these research topics. Thus, future studies should focus on gathering reproductive data for species of

commercial interest and conservation concern, along with data on length-weight relationships, in order to propose fisheries management strategies not limited to fishing ban lists.

As for fisheries itself, a decent amount of data is available (Chaves & Corrêa, 1998; Costa & Chaves, 2006; Henke & Chaves, 2017; Robert & Chaves, 2018; Chaves; Almeida & Platner, 2019; Chaves & Silva, 2019; Giareta *et al.*, 2021), configuring the most represented research area in Paraná and following the global and South American trends (Awruch; Somoza & Baldock, 2019). More specifically, the regional commercial fishing profile has been already characterized, as well as the fluctuations in catches regarding genera, sex and life stages. On the other hand, fisheries statistics data are scarce, preventing a critical analysis of the current status of regional stocks. Thus, it is necessary that annual catch volume data and catch composition at a species-specific level be prioritized, in addition to mapping and identifying areas of higher importance (i.e., parturition and nursery grounds) for the species known to occur in this region. Another very well represented area of research was diet/ feeding, with the studies carried out in Paraná being among the highlights on elasmobranch trophic ecology (Bornatowski; Robert & Costa, 2010; Bornatowski *et al.*, 2012, 2014a, 2014b; Hayata *et al.*, 2021). The access to ungutted individuals landed by the artisanal fishery fleet and the higher resistance of digestive system walls (i.e., when comparing stomachs to gonads) seemed to have favored feeding studies, generating data that could serve as a basis for further studies based on stable isotopes and stomach content DNA analysis, for example. Thus, although investigations on diet/feeding ecology are not a conservation priority, future studies on diet and trophic ecology should continue to be encouraged, aiming at increasing species' basic biology knowledge. In fact, most studies published are focused on *Carcharhinus* spp., *Sphyrna* spp., and *Pseudobatos* spp., and basic information on biology and ecology are lacking for almost all other species identified in the present study.

The topic conservation has been very little explored in the region so far, which is a call for concern considering the region's importance for the conservation of endemic elasmobranchs at the global level (Dulvy *et al.*, 2021). Paraná is also home to several threatened species, for which conservation interventions are urgent. Much has been discussed in recent years on the best strategies to conserve elasmobranch species that negatively interact with fisheries activities (Bernardo *et al.*, 2020; Wosnick *et al.*, 2020; Giareta *et al.*, 2021; Afonso & Chaves, 2021). The human dimension component was neglected for many years in decision making in Brazil, leading to a scenario of constant conflicts between commercial fishers, conservationists and policy makers. Recently, studies have shown that biodiversity co-participatory management and fishers' inclusion in research/decision-making is generating satisfactory results (Giareta *et al.*, 2021; Wosnick *et al.*, 2021). In fact, based on a risk-based mitigation hierarchy framework investigation, classic conservation interventions for elasmobranchs in India (e.g., seasonal closures, and fishing gear prohibition) tend to have less chances of success through artisanal fishers' compliance, than more dynamic and inclusive interventions, such as onboard release (Gupta *et al.*, 2020). That said, elasmobranch fisheries management in Paraná can benefit from an inclusive model, and future studies should consider the importance of traditional knowledge, as well as the participation of fishers in data collection, dissemination of scientific results and strategic fisheries decision-making.

Despite representing a very low percentage of the total number of studies (1%), medical investigations of the benefits of shark liver oil are also a concern. Among all the

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publications retrieved on this research area, the vast majority were developed by the most prominent university in the State, indicating a lack of communication between research groups regarding the problem of using shark byproducts that possibly come from species facing risk of extinction. Furthermore, considering the consumption of elasmobranch byproducts, a recent study performed in Paraná analyzed the popular perception regarding the consumption of elasmobranch meat, popularly known as "cação" (Bornatowski *et al.*, 2015). The results indicated that most people from Paraná did not know that "cação" in fact is shark or ray meat, and this was a pioneer study on elasmobranch meat mislabeling. Moreover, DNA barcoding of elasmobranchs marketed in the State indicated that many species are at risk of extinction (Bernardo *et al.*, 2020; Cruz *et al.*, 2021). Therefore, it is necessary that future studies address these issues with artisanal fishing communities and consumers. Furthermore, investigations on the production chain are needed, aiming to elucidate the economic aspects related to the elasmobranch regional trade.

As for species studied in the region, only a small portion of studies were species-specific and aimed to investigate biological/ecological aspects. Most studies only reported species presence in fishing landings, or their occurrence in the region. As stated above, elasmobranch research in Paraná strongly relies on commercial fisheries, and therefore, most studied species are the ones most commonly caught by artisanal fleets (Carcharhiniformes and guitarfishes). This way, most studied species are coastal, or have at least one life stage dependent on coastal habitats. There are reports and records of oceanic and deep-sea species in the region but there is no further information on their biology and ecology. It is suggested that future studies should focus on increasing sampling efforts and performing scientific fishing campaigns, as well as monitoring fisheries landing sites in which semi-industrial fleets disembark, aiming at increasing the knowledge on both oceanic and deep-sea species. Nevertheless, it is extremely important that studies with coastal species continue to be carried out, since the quantities of relevant information for adequate elasmobranch management in the region is still very low.

Despite being home to many elasmobranchs and having noted an increase in publications over the decades, many relevant aspects to their conservation are still not available. Thus, it is necessary that research groups interested in working with sharks and batoids in Paraná consider the knowledge gaps and study opportunities presented here. Furthermore, it is essential to prioritize basic biology data, as well as access to traditional knowledge, characterize the regional production chain and develop more robust and species-specific fisheries data. Lastly, it is also necessary that elasmobranch research in Paraná becomes less dependent on commercial fisheries, aiming to overcome the existing regional catches dynamics barriers (i.e., seasonality) and have access to other species that do not interact as intensely with commercial fleets, but still need to be investigated.

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